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Development of Fixed Time Step Analysis model for Automatic Transmission Clutch in HEV

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Abstract

A parallel hybrid electric powertrain system(HEV of PHEV) have Automatic transmission or power split device which is constructed with planetary gears and clutches. It is important to develop a model which can analysis dynamic state of clutch in shifting phase to evaluate performance of control logics. The model needs to be simulated in real time or semi-real time because every TCU is operating in fixed time step. Dynamic analysis simulation software like MSC.ADAMS or AMESIM does not satisfy real time performance. This research suggests a clutch analysis method that determines stick and slip state of clutches in an automatic transmission based on fixed step solver. A simulator model is constructed as a reference using MATLAB/SIMULNK simdriveline library. Result of simulator model is also compared with result of fixed time step analysis model.

Keywords: parallel HEV, transmission, simulation

1 Introduction

A parallel hybrid electric power train system have Automatic transmission or power split device that is constructed with planetary gears and wet friction clutches.[1,2,4] Wet clutches are widely used in automotive systems.

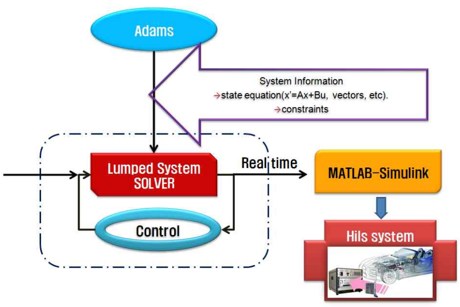


Figure1: Simple planetary gear modelling

They are essential parts of automatic transmissions, modern All-Wheel-Drive systems or dual-clutch transmissions. Regardless of the area of application, a good knowledge of clutch friction behaviors is essential for the clutch control system development.[1,2,3]

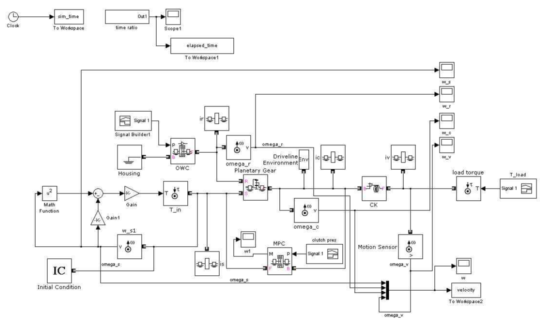


Figure2: Reference clutch model using MATLAB/SIMULINK

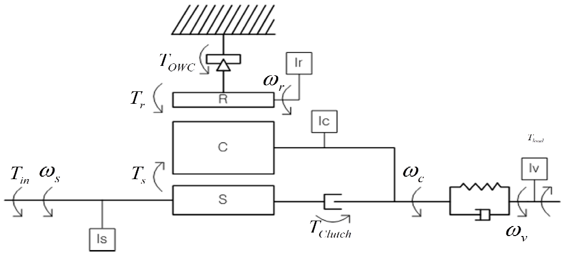


Figure3: Simple planetary gear modelling

Dynamic analysis of wet clutches has difficulty because of non linear characteristic in friction behavior.[3] Therefore it is important to develop a model that can analyze dynamic state of clutch in state transition phase (i.e. transition between engagement and disengagement) to evaluate performance of control logics. The model needs to be simulated in real time or semi-real time because every TCU is operating in fixed time step. Dynamic analysis simulation software like MSC.ADAMS or AMESIM does not satisfy real time performance.[5] This research suggests a clutch analysis method that determines stick and slip state of clutches in an automatic transmission based on fixed step solver.

A simulator model is constructed as a reference using MATLAB/SIMULINK simdriveline library and it is represented in Figure2. Result of simulator model is compared with result of fixed time step analysis model.

2 Planetary gear and clutch modelling

Automatic transmission or power split device in HEVS of PHEVs is constructed with planetary gears and clutches. [4,5,6] Figure 3 shows a single planetary gear with a clutch and one way clutch.

Equation of motion of single planetary gear is represented (1) as matrix form and (1) is transformed in state equation form (2).

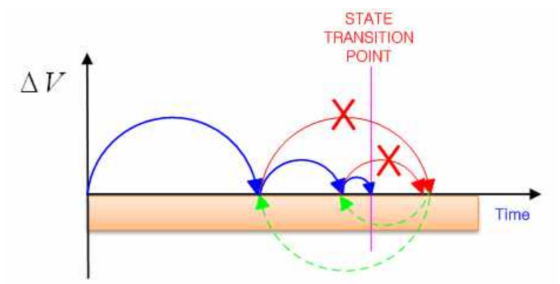


Figure4: Variable time step solver

$$\begin{bmatrix} I_s & -RI_r & 0 \\ I_c R/(1+R) & (1+R)I_r + I_c/(1+R) & 0 \\ 0 & 0 & I_v \end{bmatrix} \begin{Bmatrix} \ddot{\theta}_s \\ \ddot{\theta}_r \\ \ddot{\theta}_v \end{Bmatrix} + \begin{bmatrix} 0 & 0 & 0 \\ cR/(1+R) & c/(1+R) & -c \\ -cR/(1+R) & -c/(1+R) & c \end{bmatrix} \begin{Bmatrix} \dot{\theta}_s \\ \dot{\theta}_r \\ \dot{\theta}_v \end{Bmatrix} + \begin{bmatrix} 0 & 0 & 0 \\ kR/(1+R) & k/(1+R) & -k \\ -kR/(1+R) & -k/(1+R) & k \end{bmatrix} \begin{Bmatrix} \theta_s \\ \theta_r \\ \theta_v \end{Bmatrix} = \begin{bmatrix} 1 & 0 & -1 & -R \\ 0 & 0 & 1 & 1+R \\ 0 & -1 & 0 & 0 \end{bmatrix} \begin{Bmatrix} T_{in} \\ T_{load} \\ T_{clutch} \\ T_{OWC} \end{Bmatrix} \quad (1)$$

$$\begin{Bmatrix} \ddot{\theta} \\ \dot{\theta} \end{Bmatrix} = -\begin{bmatrix} M & 0 \\ 0 & I \end{bmatrix}^{-1} \left(\begin{bmatrix} C & K \\ -I & 0 \end{bmatrix} \begin{Bmatrix} \dot{\theta} \\ \theta \end{Bmatrix} - \begin{Bmatrix} f \\ 0 \end{Bmatrix} \right) \quad (2)$$

3 Fixed time step analysis model

Key issue of fixed time step solver for clutch is finding exact state transition point when clutch engages and disengages. State Transition Point is a moment when Stick and Slip state change.

Concept of variable time step solver is shown in Figure 4. Variable time step solver find state transition point (STP) by dividing time step size precisely and it takes too much time in analysis. ECU for transmission calculates and transmit control signal in fixed time. Therefore the variable time step solver is not suitable for on board simulation.

In order to find STP in fixed time step solver a method is developed to predict a point that state change occurs and to determines the state is stick or slip by next time step. The method determines clutch state by following step. (See Figure 5.)

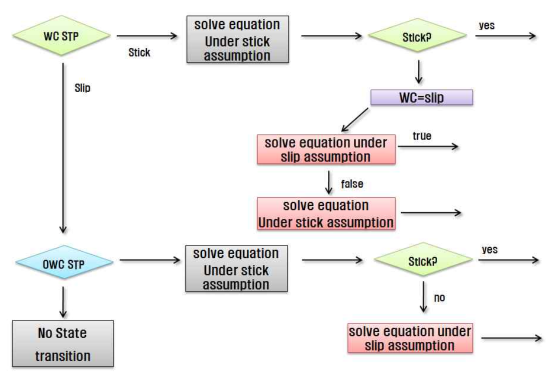


Figure5: Logic for determination stick and slip

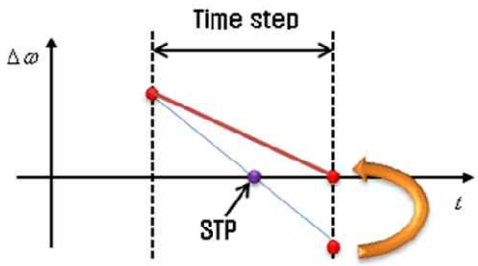


Figure6: Acceleration correction concept of fixed time step solver

First, the state of next time step is calculated by the observed of current state and time derivative of current state information. Secondly, if calculated state implied zero crossing at next step stick state is assumed. Next, clutch internal torque is calculated. If internal force is smaller than clutch capacity which is expressed as (3) the assumption would be correct. [6,7,8,9]

$$\tau_{cl} = \mu \cdot r_{eff} \cdot N_{sp} \cdot P_n \qquad (3)$$

At the time that stick is determined, in order to output proper state, calculate acceleration error and compensate the error. Concept of acceleration correction method to find STP and determine next state is represented in Figure 6.

4 Simulation and result

A Simulation model for fixed time step analysis is developed by MATLAB/SIMULINK which is represented in Figure 7. Some simulation conditions are chosen to observe clutch operation in single planetary gear. One is engagement of one way clutch and the other is engagement and disengagement of both clutches.

Simulation results are represented in Figure 8. Time step size is 10ms for fixed time step analysis. Figure 8.(a),(b) shows fixed time step analysis result and (c),(d) shows variable time step analysis. It is seen that good correlation between reference and fixed time step analysis is observed.

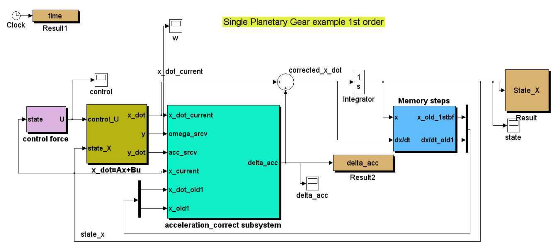
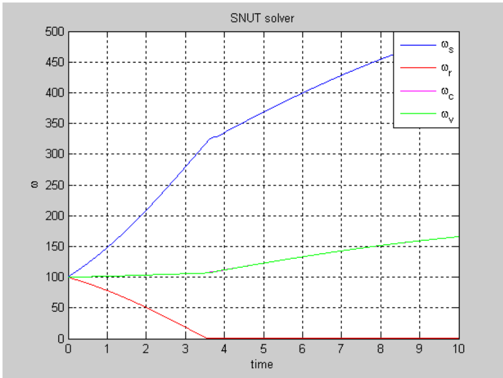
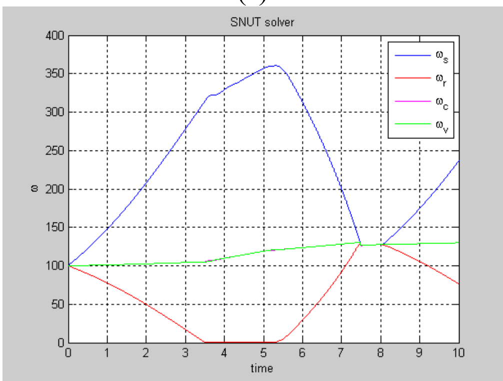


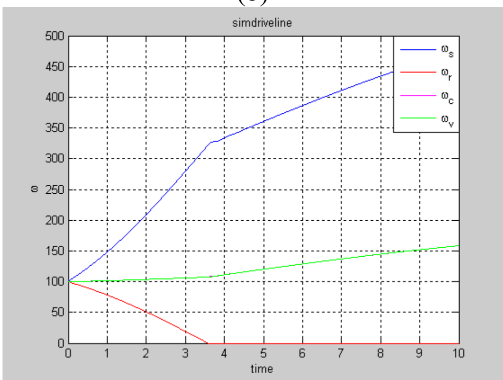
Figure7: Simulation model based on fixed time step solver



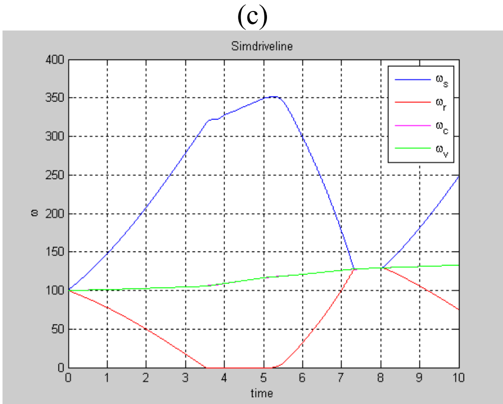
(a)



(b)



(c)



(d)

Figure8: simulation results of the one way clutch(OWC) and wet clutch(WC) engagement and disengagement (a),(b) OWC/WC operation fixed time step solver (c),(d) those of variable time step solver

5 Conclusion

This research suggest a dynamic analysis method of automatic transmission which is composed with wet friction clutches and planetary gears based on fixed time step solver in order to construct on board transmission control logic. A method that corrects acceleration is suggested to find STP accurately and to output proper state.

A simulator model is constructed to analysis operation of a transmission with clutches and planetary gears using MATLAB/SIMULINK. Results of reference model are compared with fixed time step analysis model.

The results have been shown above implies that the fixed time step analysis model found STP accurately and determine dynamic state(stick or slip) of clutches at next time step.

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